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PHOTOMETRIC OBSERVATIONS OF SUPERNOVAE 2000E, 2001B, 2001V, AND 2001X

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Abstract

CCD *BVRI* photometry is presented for two type Ia supernovae 2000E and 2001V, for SN Ib 2001B and SN II-P 2001X. The parameters of light curves and absolute magnitudes at maximum light are estimated. It is shown that all four supernovae are typical for their classes considering the shape of their light curves and maximum luminosity.

Introduction

Continuing the long-term program of supernova (SN) observations at Sternberg Astronomical Institute, we carried out photometry of bright SNe 2000E, 2001B, 2001V and 2001X.

SN 2000E was discovered by Valentini et al. (2000) at magnitude V=14.3 on CCD images obtained with the Teramo 0.72-m TNT telescope on January 26.73 UT. SN was located at $\alpha = 20^{\rm h}37^{\rm m}13^{\rm s}.8, \delta = +66^\circ05'50''.2$ (equinox 2000.0), which is $6''.3$ west and $26''.7$ south of center of the Sbc galaxy NGC 6951. Turatto et al. (2000) reported that spectra obtained with 1.8-m telescope at Cima Ekar on January 27.83 UT indicated that SN 2000E was type Ia event, few days before maximum light. CCD photometry of this SN was reported by Vinko et al. (2001) and Valentini et al. (2003).

The discovery of SN 2001B was reported by Xu and Qiu (2001) on behalf of Beijing Astronomical Observatory SN survey on January 3.61 UT at magnitude 15.5, estimated from unfiltered CCD image. SN was located at $\alpha = 4^{\rm h}57^{\rm m}19^{\rm s}.24, \delta = +78^\circ11'16''.5$ (equinox 2000.0), which is $5''.6$ west and $8''.9$ south of the nucleus of Sc galaxy IC 391. Chornock and Filippenko (2001) reported that spectra of SN 2001B, obtained on January 23 with the Shane 3-m reflector at Lick Observatory, revealed that the object was probably a type Ib SN, roughly one week past maximum brightness.

SN 2001V was discovered by Berlind on February 19.38 UT with the F. L. Whipple Observatory 1.5-m telescope (Jha et al., 2001). The following precise position was determined for SN 2001V: $\alpha = 11^{\rm h}57^{\rm m}24^{\rm s}.93, \delta = +25^\circ12'09''.0$ (equinox 2000.0), which is $52''$ east and $28''$ north of the nucleus of edge-on Sb galaxy NGC 3987. The spectrum of SN exhibited a blue continuum with broad features, identifying this as a type-Ia SN well before maximum light. Photometry of SN 2001V was later reported by Vinko et al. (2003).

The discovery of SN 2001X was reported by Li et al. (2001) on behalf of Beijing Astronomical Observatory SN survey. The object was found (magnitude about 17.0) on

an unfiltered image taken with the BAO 0.6-m telescope on February 27.8 UT. SN 2001X was located at $\alpha = 15^{\rm h}21^{\rm m}55^{\rm s}.45, \delta = +5°03'42''.1$ (equinox 2000.0), which is $15''.5$ west and $32''.4$ south of the nucleus of Sbc galaxy NGC 5921. Chornock et al. (2001) reported that a spectrum of SN 2001X, obtained with the Lick Observatory Shane 3-m telescope on March 3.5 UT under poor conditions, showed a very blue continuum with strong H Balmer lines, indicating that it was a type-II SN before maximum light.

Observations and reductions

The observations were carried out at 60-cm reflector of Crimean Observatory of Sternberg Astronomical Institute (C60) using SBIG ST-7 CCD camera and with 30-cm refractor (M30) and 70-cm reflector (M70), both with SBIG ST-6 camera, in Moscow. All reductions and photometry were made using IRAF.†

The color terms for transformation of instrumental magnitudes $bvri$ to standard BVR_cI_c were determined for different observing seasons and telescope-filter-detector combinations using observations of standards in M 67 (Chevalier and Ilovaisky, 1991) and in NGC 7790 (Stetson, 2000). The equations $b = B + K_b(B-V) + C_b; v = V + K_v(B-V) + C_v; r = R + K_r(V-R) + C_r; i = I + K_i(R-I) + C_i$ were solved for color terms, which are listed in Table 1. The images of SNe with comparison stars are shown in Figs. 1-4. The magnitudes of comparison stars were determined on photometric nights, when we observed standards from Landolt (1992) and standard regions in clusters M 67, NGC 7790, and M 92 (`http://cadcwww.hia.nrc.ca/cadcbin/wdb/astrocat/stetson/query/ NGC6341`). Some magnitude estimates for comparison stars were obtained during observations of SNe, but they were verified later, in 2002-2004, using observations on C60 and M70 equipped with CCD cameras Apogee AP-7p and Ap-47p; Roper Scientific VersArray1300B. Final values for magnitudes of comparison stars were determined by averaging data from 5-8 nights; they are presented in Table 2, where the designations of stars consist of the galaxy name and the star number on the chart.

Photometric measurements of SNe were made relative to comparison stars using PSF-fitting with IRAF DAOPHOT package. The background of host galaxies around SNe was quite smooth in most cases, which was not surprising, taking into account high focal ratio of our telescopes. Subtraction of images of host galaxies, obtained when SNe were no longer detectable, was applied in some cases for SNe 2001B and 2001X, and the results were found practically identical to those obtained without subtraction. The results of SNe observations are presented in Tables 3-6, and the light curves are shown in Figs. 5-8.

Results and conclusions

SN 2000E. The light curves are shown in Fig. 5. They appear typical for SN Ia, the data are in good agreement with the template light curves of SN Ia 1991T (Lira et al., 1998), except that the decline rate at late stage for SN 2000E is higher than for SN 1991T. Our magnitudes are in good agreement with results of Valentini et al. (2003) and Vinko et al. (2001). But our B magnitude of comparison star 1 differs significantly from the value given by Vinko et al. (2001): $\Delta B = 0.18$. The magnitudes of SN at maximum light and at the inflection point can be determined: $B_{max} = 14.35$ on JD 2451577, $V_{max} = 13.80$ on JD 2451579, $R_{max} = 13.50$ on JD 2451577, $I_{max} = 13.55$ on JD 2451575, $B_K = 17.1$ on JD

†IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation

2451607. SN 2000E had quite slow decline past maximum: $\Delta m_{15}(B) = 0.95$, $\beta_B = 0.083$ mag/day, $\beta_V = 0.05$. But the rate of decline after the inflection point was close to the mean values for SNe Ia: $\gamma_B = 0.015, \gamma_V = 0.019, \gamma_R = 0.027$.

SN 2000E clearly suffered significant extinction both in our Galaxy and in the host galaxy. The Galactic extinction in the direction of NGC 6951 is $A_B = 1.57$ according to Schlegel et al. (1998), but Burstein and Heiles (1982) gave much smaller value $A_B = 0.88$. Valentini et al. (2003) reported that interstellar NaID lines in the spectrum of SN 2000E, which originated in the host galaxy, had equivalent width EW(NaI)$\sim$ 0.6 Å. According to Turatto et al. (2003) this value of EW(NaI) may correspond to color excess $E(B-V)$ from 0.1 to 0.3 magnitudes. So, using these data, we can estimate total reddening of SN 2000E to lie between 0.32 and 0.70. Comparing the color $(B-V)$ curve of SN 2000E with the color curves for SNe Ia with negligible extinction in host galaxies, we can estimate $E(B-V) \approx 0.6$. Valentini et al. (2003) have adopted $E(B-V) = 0.5$ as the most likely value, after considering different methods for its determination. If we take this value for reddening and distance modulus $\mu = 31.93$ from LEDA (`http://leda.univ-lyon1.fr/`), which is computed using radial velocity of the host galaxy, corrected for Virgocentric flow, and $H_0 = 70$ km s^{-1}Mpc^{-1}, then we obtain for absolute magnitude of SN 2000E $M_B = -19.6, M_V = -19.7$. This is clearly brighter than average value for SNe Ia and confirms the relation between rate of decline and absolute magnitude for SNe Ia (Pskovskii, 1977, Phillips, 2005).

SN 2001B. The light curves are shown in Fig. 6, where we also plotted the data, reported by amateur astronomers at
`http://www.astrosurf.com/snweb2/2001/01B_/01B_Meas.htm`. Their results are in satisfactory agreement with our data, and we can assume that the peak of R-band light curve is correctly determined by observations of amateurs. Supposing the V light curve had the same shape of the peak, we fitted it with V-band light curve of SN Ib 1983N (Cappellaro et al., 1995), and the agreement seems quite satisfactory. We can estimate the magnitudes at maximum light: $V_{max} = 15.0$ on JD 2451929, $R_{max} = 14.4$ on approximately the same date. The rate of linear decline after the inflection point was ~ 0.015 mag/day both in V and R bands. It is difficult to estimate extinction in the host galaxy for SN 2001B, because color curves of type Ib/c SNe have considerable scatter. But in this case we can suppose that it was not large, because reports on spectroscopic observations did not mention noticeable NaI interstellar lines and $(B-V)$ color near maximum was quite blue: ~ 0.1 mag. Adopting distance $\mu = 32.07$ from LEDA, Galactic extinction $A_B = 0.55$ from Schlegel et al. (1998), we derive $M_V = -17.5$, which is close to the mean value for SN Ib/c (Richardson et al., 2002)

SN 2001V. The light curves, presented in Fig. 7, can be matched closely by those for SN 1991T. Our data are in good agreement with the results by Vinko et al. (2003), only in the R band some systematic difference can be noticed. Our magnitudes for comparison star 1 are in excellent agreement with data by Vinko et al. (2003), with maximum difference of only 0.01 mag. The magnitudes at maximum light can be determined from template curve fitting, as there was a gap in observations near maximum: $B_{max} = 14.7, V_{max} = 14.6, R_{max} = 14.7, I_{max} = 14.9$. The time of maximum in B was about JD 2451974. SN 2001V was clearly a slow declining SN Ia, but as the maximum was not covered with observations, we would not attempt to derive $\Delta m_{15}(B)$, but estimate only $\beta_V = 0.053$. This value is similar to the one for SN 2000E. The extinction for SN 2001V is very small both in our Galaxy and in the host galaxy: Galactic $A_B = 0.085$ according to Schlegel et al. (1998), and the color curve $(B-V)$ does not show significant

reddening. Vinko et al. (2003) derived total reddening $E(B-V) = 0.05$. Adopting this value and distance modulus $\mu = 34.11$ from LEDA, we obtain $M_B = -19.6, M_V = -19.7$ – the same values as for SN 2000E. So photometric characteristics of these two SNe Ia are nearly identical.

SN 2001X. This SN was certainly a type II-P event, as can be seen from Fig. 8, where we also plotted data obtained by amateur astronomers in the bands close to V and R from `http://www.astrosurf.com/snweb2/2001/01X_/01X_Meas.htm`. Most of their magnitudes are in good agreement with our results. The light curves are fitted with those for typical SN II-P 1999gi (Leonard et al., 2002). We can estimate $B_{max} = 15.2$ on JD 2451974, $V_{max} = 15.2, R_{max} = 14.9, I_{max} = 14.7$. The plateau phase lasted approximately until JD 2452077, that is about 103 days, which is quite typical value for type II-P SNe. The Galactic extinction in direction of SN 2001X amounts to $A_B = 0.173$ according to Schlegel et al. (1998). Comparison of color $(B-V)$ curve for SN 2001X with the one for SN 1999gi allows to conclude that reddening of SN 2001X in the host galaxy was negligible. Adopting $\mu = 31.77$ from LEDA, we estimate $M_B = M_V = -16.7$, close to the mean value for SN II-P (Richardson et al., 2002).

The results of our study show that all investigated SNe are typical for their classes considering the shape of their light curves and absolute magnitudes at maximum.

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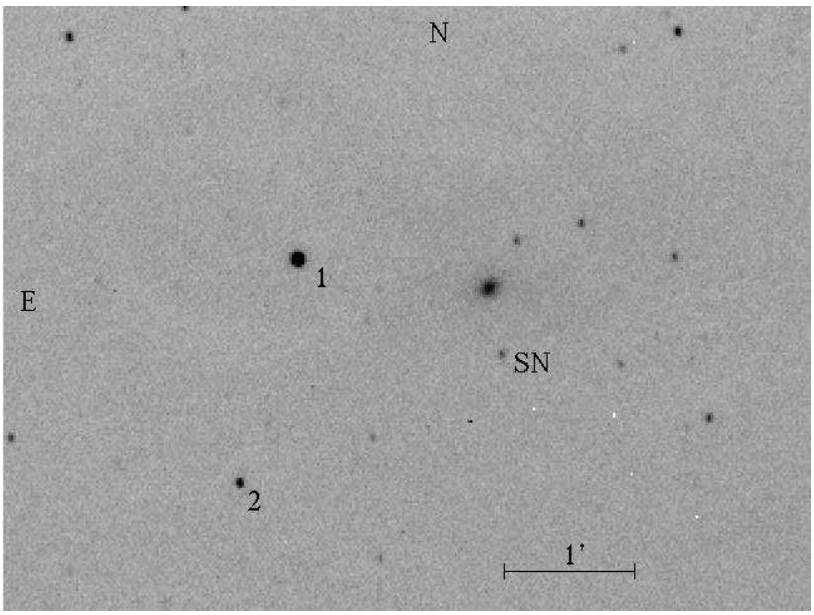

Figure 1. SN 2000E in NGC 6951 with comparison stars

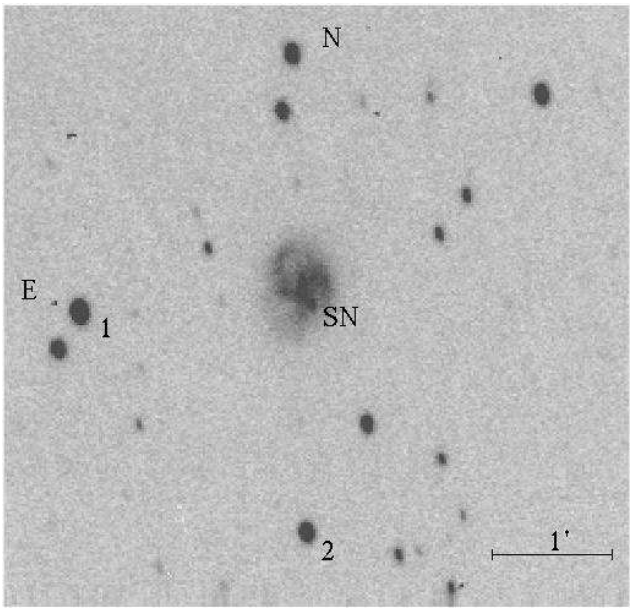

Figure 2. SN 2001B in IC 391 with comparison stars

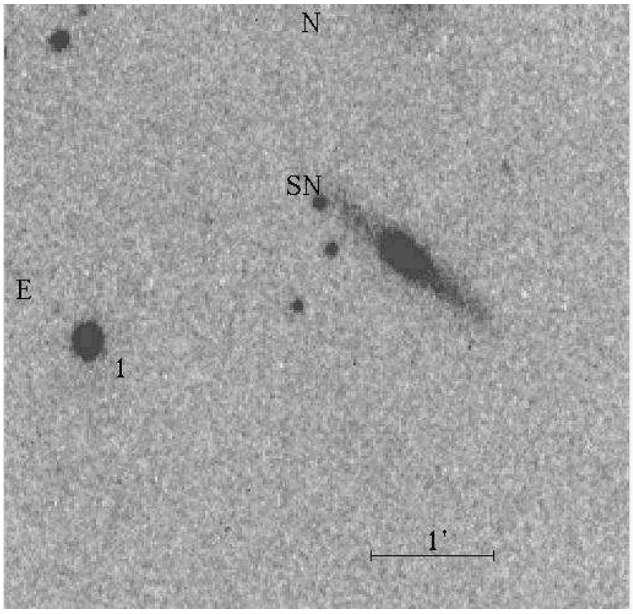

Figure 3. SN 2001V in NGC 3987 with comparison star

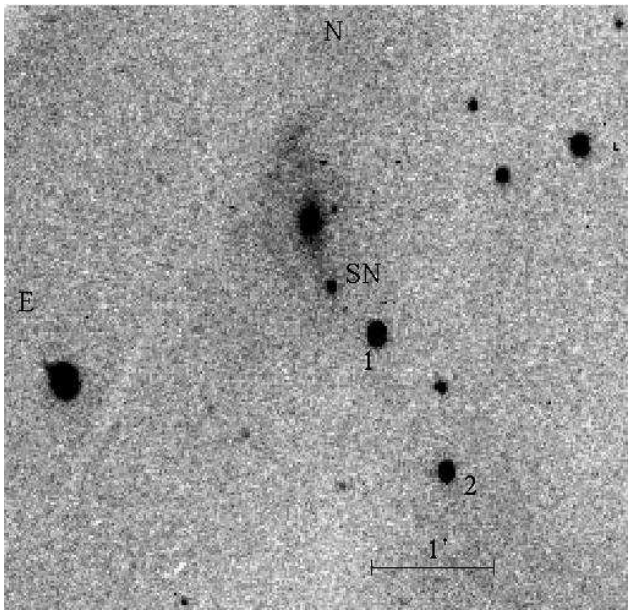

Figure 4. SN 2001X in NGC 5921 with comparison stars

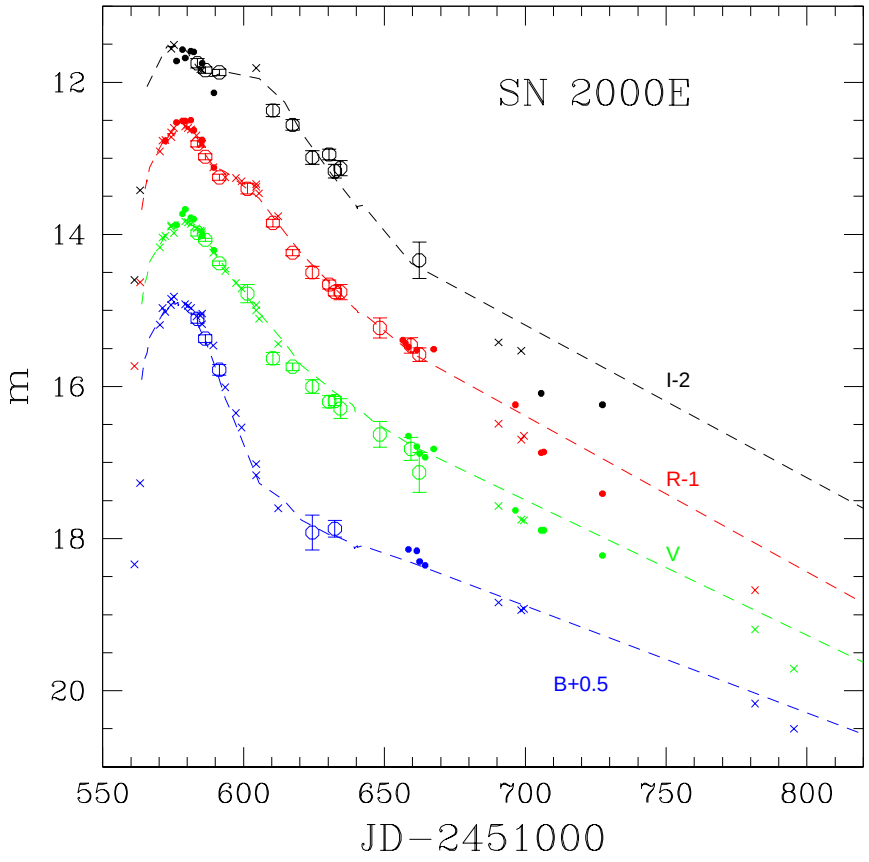

Figure 5. *BVRI* light curves of SN 2000E, showing our photometry (circles) and that of Vinko et al. (2001) (dots) and Valentini et al. (2003)(crosses). The dashed lines are the light curves of SN 1991T

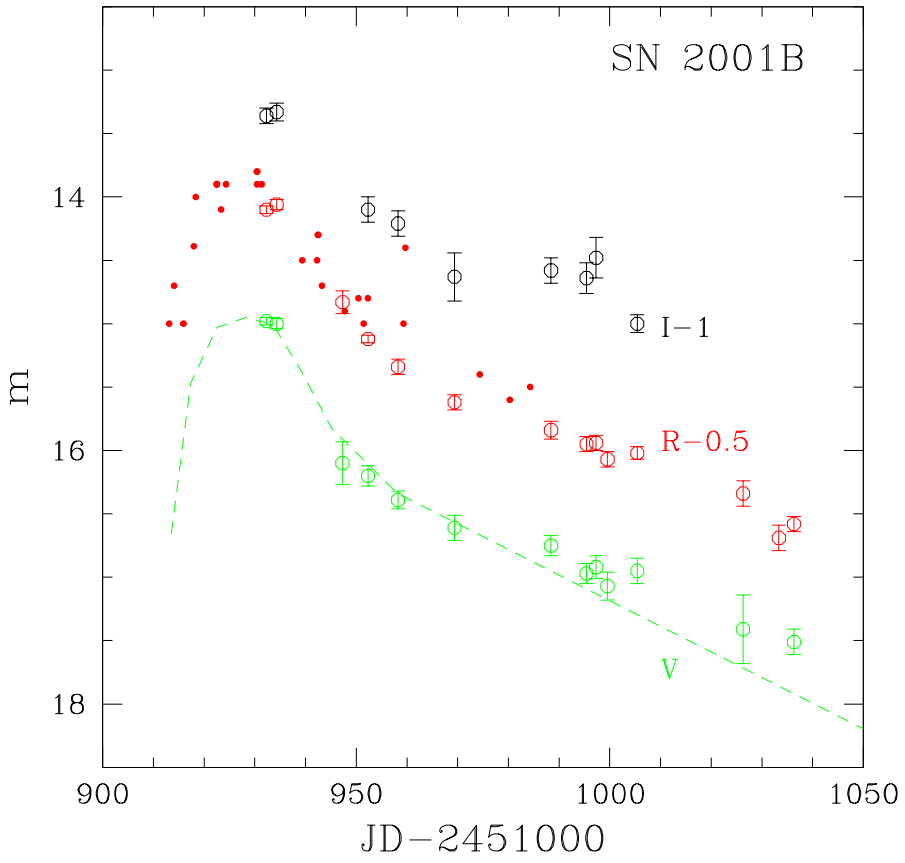

Figure 6. *VRI* light curves of SN 2001B. Circles show our data, dots are for the observations of amateur astronomers. The dashed line is *V* light curve of SN 1983N

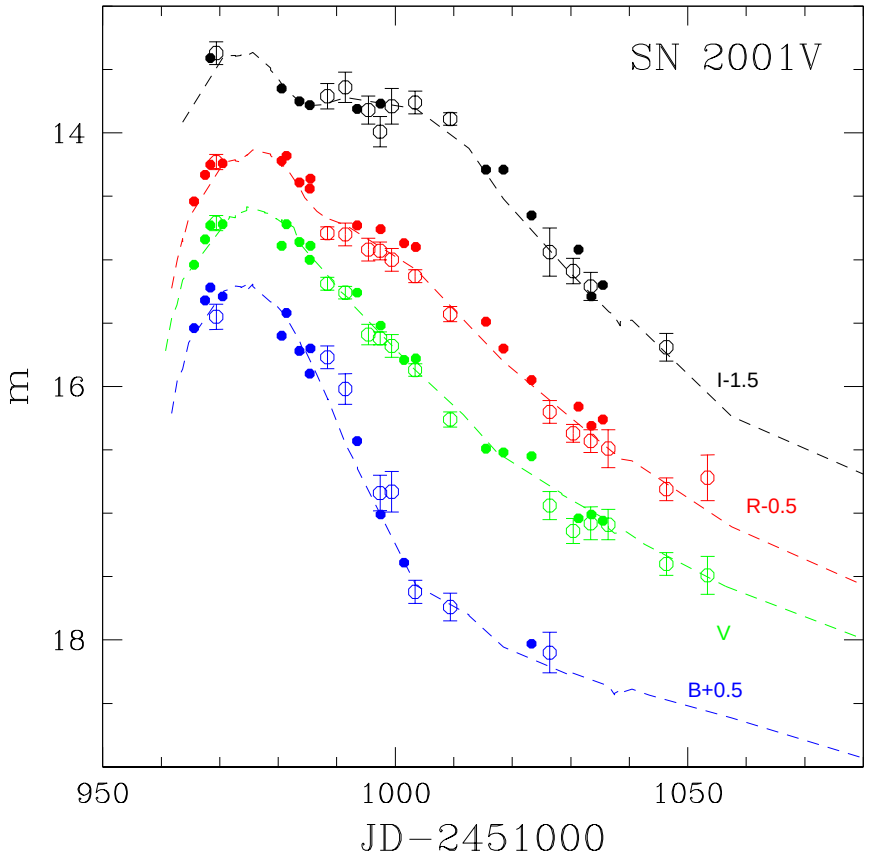

Figure 7. *BVRI* light curves of SN 2001V, showing our photometry (circles) and that of Vinko et al. (2003)(dots). The dashed lines are the light curves of SN 1991T

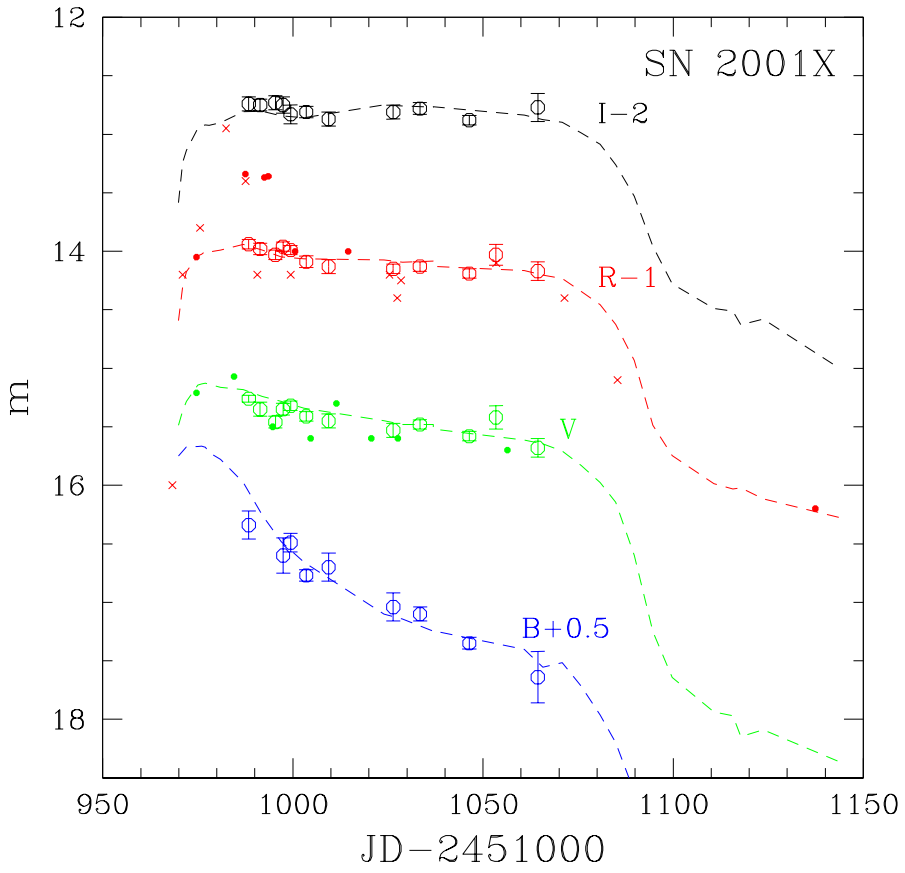

Figure 8. *BVRI* light curves of SN 2001X. Circles show our data, dots are for observations of amateur astronomers in V and R bands, crosses show photometry by amateurs with unfiltered CCDs. The dashed lines are the light curves of SN 1999gi

Table 1: Color terms for reduction equations

Tel., year	K_b	K_v	K_R	K_i
C60, 2000	-0.53	-0.045	-0.50	-0.53
M30, 2000	-0.32	-0.046	-0.56	-0.06
M30, 2001	-0.31	-0.002	-0.42	-0.23
M70, 2001	-0.11	-0.008	-0.34	-0.39

Table 2: Magnitudes of comparison stars

Star	B	σ_B	V	σ_V	R	σ_R	I	σ_I
NGC6951-1	14.35	0.02	12.61	0.02	11.67	0.02	10.86	0.03
NGC6951-2	15.75	0.04	14.91	0.02	14.36	0.04	13.91	0.04
IC391-1	14.01	0.08	13.24	0.02	12.85	0.01	12.50	0.04
IC391-2	14.85	0.10	14.07	0.03	13.66	0.02	13.21	0.06
NGC3987-1	13.08	0.05	12.23	0.01	11.74	0.01	11.27	0.03
NGC5921-1	13.22	0.03	11.99	0.01	11.33	0.01	10.71	0.03
NGC5921-2	13.51	0.04	12.90	0.02	12.57	0.02	12.24	0.05

Table 3: Observations of SN 2000E

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
1583.62	14.61	0.06	13.98	0.04	13.81	0.04	13.75	0.06	C60
1586.61	14.87	0.05	14.07	0.02	13.98	0.04	13.84	0.04	C60
1591.60	15.28	0.07	14.38	0.03	14.25	0.04	13.87	0.04	C60
1601.60			14.78	0.12	14.40	0.07			M30
1610.60			15.63	0.08	14.85	0.05	14.37	0.08	M30
1617.57			15.74	0.05	15.24	0.04	14.56	0.07	M30
1624.57	17.42	0.23	16.00	0.09	15.50	0.08	14.99	0.09	M30
1630.58			16.20	0.08	15.66	0.06	14.95	0.07	M30
1632.53	17.37	0.11	16.19	0.06	15.76	0.05	15.17	0.09	M30
1634.53			16.29	0.13	15.76	0.10	15.13	0.10	M30
1648.39			16.63	0.17	16.23	0.13			M30
1659.41			16.82	0.15	16.46	0.10			M30
1662.40			17.13	0.26	16.58	0.09	16.34	0.24	M30

Table 4: Observations of SN 2001B

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
1932.29	15.27	0.15	14.98	0.03	14.60	0.03	14.36	0.06	M30
1934.30	14.94	0.18	15.00	0.04	14.56	0.04	14.33	0.07	M30
1947.30			16.10	0.17	15.33	0.09			M30
1952.32			16.20	0.08	15.62	0.03	15.10	0.10	M30
1958.25			16.39	0.07	15.84	0.06	15.21	0.10	M30
1969.39			16.61	0.10	16.12	0.06	15.63	0.19	M30
1988.41			16.75	0.08	16.34	0.07	15.58	0.10	M30
1995.40			16.97	0.08	16.45	0.06	15.64	0.12	M30
1997.31			16.92	0.09	16.44	0.06	15.48	0.16	M30
1999.55			17.07	0.11	16.57	0.06			M30
2005.41			16.95	0.10	16.52	0.05	16.00	0.07	M70
2026.31			17.41	0.27	16.84	0.10			M70
2033.35					17.19	0.10			M70
2036.32			17.51	0.10	17.08	0.06			M70

Table 5: Observations of SN 2001V

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
1969.55	14.95	0.10	14.71	0.06	14.73	0.06	14.87	0.09	M30
1988.47	15.27	0.09	15.19	0.05	15.29	0.05	15.21	0.10	M30
1991.45	15.52	0.12	15.26	0.05	15.30	0.09	15.14	0.12	M30
1995.45			15.59	0.08	15.42	0.09	15.32	0.11	M30
1997.40	16.34	0.14	15.62	0.05	15.43	0.07	15.49	0.12	M30
1999.44	16.33	0.16	15.68	0.09	15.50	0.09	15.29	0.14	M30
2003.47	17.12	0.09	15.87	0.05	15.63	0.05	15.26	0.09	M70
2009.41	17.24	0.11	16.26	0.06	15.93	0.06	15.39	0.05	M70
2026.37	17.60	0.16	16.94	0.11	16.70	0.09	16.44	0.19	M70
2030.32			17.14	0.10	16.87	0.07	16.59	0.10	M70
2033.41			17.08	0.13	16.93	0.09	16.71	0.11	M70
2036.41			17.09	0.12	16.99	0.15			M70
2046.34			17.40	0.09	17.31	0.09	17.19	0.11	M70
2053.38			17.49	0.15	17.22	0.18			M30

Table 6: Observations of SN 2001X

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
1988.57	15.84	0.12	15.26	0.03	14.94	0.04	14.74	0.06	M30
1991.50			15.35	0.06	14.98	0.05	14.75	0.06	M30
1995.51			15.46	0.05	15.03	0.04	14.73	0.06	M30
1997.46	16.10	0.15	15.35	0.05	14.96	0.04	14.75	0.07	M30
1999.50	15.99	0.08	15.32	0.04	14.99	0.04	14.83	0.08	M30
2003.51	16.27	0.06	15.41	0.04	15.09	0.05	14.81	0.05	M70
2009.53	16.20	0.12	15.45	0.06	15.13	0.06	14.87	0.06	M70
2026.46	16.54	0.12	15.53	0.06	15.15	0.04	14.81	0.06	M70
2033.46	16.60	0.07	15.48	0.04	15.13	0.04	14.78	0.05	M70
2046.43	16.85	0.06	15.58	0.04	15.19	0.04	14.88	0.05	M70
2053.42			15.42	0.10	15.03	0.09			M30
2064.40	17.14	0.22	15.68	0.08	15.17	0.08	14.77	0.12	M30